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by

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INFLUENCES OF ATMOSPHERIC TURBULENCE ON LASER RADAR TRACKING ANGLE ERRORS

Dai Yongjiang Cheng Xiangyang Zhao Yuan Wang Yan Cai Xiping

Translation of "Da Qi Tuan Liu Dui Ji Guang Lei Da Gen Zong Jiao Wu Cha De Ying Xiang"; pp 175-178

ABSTRACT This article discusses the influences of intensity fluctuations and phase fluctuations given rise to by atmospheric turbulence on the precision of laser radar tracking system angle measurements. Making use of logarithmic amplitude variances led to by intensity fluctuations as well as arrival angle variances led to by phase fluctuations, calculations are done of the influences of intensity fluctuations and phase fluctuations on reception signal to noise ratios and angular errors associated with tracking systems. Results clearly show that there are relationships between factors such as angular errors given rise to by atmospheric turbulence and angles of elevation, ranges, and so on.

KEY WORDS Laser radar Measurement angle precision Atmospheric turbulence

1 INTRODUCTION

Following along with the development of laser technology, laser radars have achieved broad applications in such areas as target range measurement and control, guidance, flight obstacle ranging (illegible), terrain tracking, and so on. However, in applications of laser radar, laser radars generally make use of four quadrant tracking survey systems in order to achieve angular tracking of targets. Atmospheric turbulence influences the quality of laser transmission, thereby giving rise to angular errors associated with tracking systems. From such aspects as quantum noise, background noise, dark current noise, detector and electronic circuitry thermal noise, and so on, Reference [1] discusses tracking precisions associated with four quadrant tracking detection systems. However, consideration was not given to influences associated with atmospheric transmission. The Anhui photomechanical institute [2] discussed the influences of intensity fluctuations and phase fluctuations given rise to by atmospheric turbulence on angular tracking precisions. During the processes of actual tracking, it is usually necessary to carry out measurements of targets associated with different angles of elevation and ranges. As a result, discussion should be made of the relationships of angular errors given rise to by atmospheric

turbulence and such factors as angles of elevation and ranges. This article discusses in a comparatively comprehensive way the influences, at different elevation angles and ranges, of intensity fluctuations and phase fluctuations given rise to by atmospheric turbulence as well as noise produced by reception systems themselves. These possess a guiding significance with regard to the popularization and application of laser radars.

2 THEORY

Assuming that errors associated with laser radar reception and servo systems themselves are precisely specified, that pitch and azimuth axes are relatively symmetrical, and, in conjunction with that, that they are normally placed in accurate alignment, then, amounts of angular target miss in the x and y directions are symmetrical--that is, one has:

$$\theta_t = \sqrt{\theta_x^2 + \theta_y^2} = \sqrt{2}\theta \tag{1}$$

The subscript t stands for total amounts of angular miss.

As far as TEMoo mode laser beams fired by lasers toward targets are concerned, after transmission a certain distance in the atmosphere, due to random fluctuations associated with such parameters as atmospheric temperature, index of refraction, and so on--in terms of space and time--beam intensity and phase show the appearance of random distributions. This is then equivalent to introducing intensity fluctuation and phase fluctuation noise into signal beams, lowering signal to noise ratios associated with reception and transmission beams. In conjunction with this, certain tracking errors are given rise to. Angular tracking errors and signal to noise ratios SNR have the relationship below.

$$\theta = C/SNR \tag{2}$$

In this, C is a proportionality coefficient. It is the tracking system amount of angular target miss when the system signal to noise ratio is 1 as a numerical value.

Assuming that the total angular error given rise to by atmospheric transmission is θ_t, the half angle errors given rise to respectively by intensity fluctuations and phase fluctuations are θ_i and θ_s. These two components are statistically independent. One then has: /176

$$\theta_t = \sqrt{2}\sqrt{\theta_i^2 + \theta_s^2} \tag{3}$$

1) Influences of Intensity Fluctuations

For the sake of simplicity, assume that, before transmitted beams enter into photoelectric detectors and are received, the various types of noise during reception processes are then superimposed on signal beams. Stipulate that the complex output amplitudes associated with detectors are:

$$r = y + n \tag{4}$$

In the equation, y is the contribution of target echo. Due to influences associated with atmospheric turbulence, intensity fluctuations contained in target echoes as well as phase fluctuation noise are also square law detected due to photoelectric detection devices. The y term only contains information and intensity fluctuation noise. n is a zero average value complex number random Gaussian distribution variable standing for the sum of such system noises as reception process background noise, dark current noise, detector and electronic circuitry thermal noise, and so on.

Define
$$SNR = \langle |y|^4 \rangle / Var(|r|^4) \tag{5}$$

Carrier noise ratio
$$CNR = \langle |y|^2 \rangle / \langle |n|^2 \rangle \tag{6}$$

Saturation noise ratio
$$SNR_{sat} = \langle |y|^2 \rangle^2 / Var(|y|^2) \tag{7}$$

One then has
$$SNR = \frac{CNR/2}{1 + CNR/2SNR_{sat} + (2CNR)^{-1}} \tag{8}$$

In the equation, as far as $\langle |n|^2 \rangle$ is concerned, it is possible to substitute in a fixed value. It is only necessary to solve for $\langle |y|^2 \rangle$ and $Var(|y|^2)$, and that will do.

Assuming that atmospheric transmission paths are a random spacial system unrelated to time and when consideration is not given to influences coming from targets:

$$|y|^2 = |y^0|^2 \exp[4x(\rho', 0)] \tag{9}$$

In this, y^0 is the contribution of target echoes in clear atmosphere without turbulence. Intensity fluctuation factors are represented by exponential terms. $x(\rho',0)$ is an average value of $-\sigma_x^2$. Variances are random normal distribution variables associated with σ_x^2 [3], standing for logarithmic amplitude fluctuations. On the basis of $x(\rho',0)$, it is possible, after going through averaging associated with diffusion target reflection, to define the random logarithmic amplitude fluctuation variable u.

$$e^{2u} = \frac{\int d\rho' \, |\zeta_t^2(\rho')|^2 T_s(\rho') \exp[4x(\rho', 0)]}{\int d\rho' \, |\zeta_t^2(\rho')|^4 T_s(\rho') \exp(4\sigma_x^2)} \tag{10}$$

In the equation, ρ' is a target planar position vector. $\zeta t(\rho')$ is a normalized target planar field mode produced after transmission through free space of a normalized spacial mode sent out by transmitting devices. $T_r(\rho')$ is a pure diffusion reflection target reflecting system. From the definition of u, it is possible to know that the average value is $-\sigma^2$. Variance is σ^2, also satisfying:

$$\exp(4\sigma^2) - 1 = \zeta[\exp(16\sigma_x^2) - 1] \quad (11)$$

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In this, ζ is called the symmetrical amplitude aperture average factor.

The expression associated with $|y|^2$ can be changed by equation (8) to be:

$$|y|^2 = |y^0|^2 \exp(4\sigma_x^2)\, v\, e^{2u} \quad (12)$$

In the equation, v is a logarithmic random variable with an average value of 1. It is statistically unrelated to u. It represents target faculae spreading. Moreover, u stands for scintillation caused by turbulence.

Through derivation:

$$\langle |y|^2 \rangle = |y^0|^2 \exp(4\sigma_x^2) \quad (13)$$

$$\mathrm{Var}(|y|^2) = |y^0|^4 \exp(8\sigma_x^2)\{1 + 2\zeta[\exp(16\sigma_x^2) - 1]\} \quad (14)$$

$|y^0|^2$ can be obtained from the equation below.

$$|y^0|^2 = \lambda^2 \eta P/h\mu_0 \cdot d^2/4 \int d\rho' \, |\zeta_t^2(\rho')|^2 T_r(\rho') \exp(-2aL) \quad (15)$$

In equations, P_T is pulse peak value power. η is photoelectric detector quantum yield. h is Planck's constant. μ_0 is emission frequency. λ is wave length. d is emission antenna diameter. a is atmospheric absorption coefficient. L is the one way transmission path.

From the derivations above, it is possible to know that an analysis of the influences of amplitude fluctuations on signal to noise ratios is calculated on the basis of logarithmic amplitude variances caused by turbulence.

$$\sigma_x^2 = 0.563K^{7/6} C_{n0}^2 \int_0^L dz \{h^{-2/3} \exp(-h/b)\} [(z/L)(L-z)]^{5/6} \quad (16)$$

In equations, $h = h_o + (L-z)(H-h_o)/L$

Generally, during turbulence situations, $Cno^2 = 4\times10^{-14}$, b=2500.

During cases of comparatively strong turbulence, $Cno^2 = 10^{-12}$,

b=4000.
h_o is target height. H is emiter height. L is slant range.

2) Phase Fluctuations

Root mean square noise currents i_c given rise to by arrival angle fluctuations on detectors are [2]:

$$i_c=\sqrt{4\sigma_a^2}\, i_1/C \qquad \sqrt{1+\sigma_a^2}\; i_1/C \tag{17}$$

Signal to noise ratios on four quadrant detectors:

$$SNR=2\, i_1/i_c \tag{18}$$

Opting for the use of Von Karman turbulence spectra, arrival angle fluctuation variances σ_a^2 associated with spherical wave surfaces on slanted light paths are [4] /178

$$\sigma_a^2=2.914\rho^{-1/3}C_{n0}^2\int_0^L dz[h^{-2/3}\exp(-h/b)][(1/L)(L-z)]^{5/6} \tag{19}$$

3 CONCLUSIONS

We gave primary consideration to the influences of atmospheric turbulence on slant paths included within angles of ±20° from a horizontal direction. Angular target miss amounts given rise to by intensity fluctuations are calculated from such equations as (2), (5), (13), (14), (15), (16), and so on. The influences of phase fluctuations are calculated from equations (18) and (19). The laser wave length which is used is 1.06μm. Pulse peak value power is 20mw. Photoelectric detector quantum yield is 0.5. Transceiver antenna apertures are 150mm. Atmospheric absorption coefficient is $0.3km^{-1}$. Target diffusion reflection coefficient is 0.02 (illegible). We first assume that emitting device heights and target heights are given--respectively, 100m and 10m. However, slant ranges and angles of slope change. Calculation results are seen in Fig.1. After that, adoption is made of different emitting device heights and target heights. With each set of heights, calculations are again respectively made of the situations associated with different slant ranges. Above, in all cases, a distinction is made in the calculation of two situations--general turbulence intensities and comparatively strong turbulence intensities.

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